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RESEARCH MEMORANDUM

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Bureau of Aeronautics, Department of the Navy

FREE-SPINNING-TUNNEL TESTS OF A $\frac{1}{24}$ -SCALE MODEL OF THE
GRUMMAN XF9F-2 AIRPLANE WITH WING-TIP TANKS INSTALLED

By

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By Theodore Berman and Jack H. Wilson

SUMMARY

An investigation of the spin and recovery characteristics of a $\frac{1}{24}$ -scale model of the Grumman XF9F-2 airplane with wing-tip tanks installed has been conducted in the Langley 20-foot free-spinning tunnel. The effects of control settings and movements on the erect spin and recovery characteristics of the model for a range of possible loadings of the tip tanks were determined. Spin and recovery characteristics without tanks were determined in a previous investigation.

The model results indicated that the airplane spins will generally be oscillatory and that recoveries will be satisfactory for all loadings by normal recovery technique (full rudder reversal followed approximately one-half turn later by moving the elevator down). The rudder force necessary for recovery should be within the physical capability of the pilot but the elevator force may be excessive so that some type of balance or booster might be necessary, or it might be necessary to jettison the wing-tip tanks.

INTRODUCTION

On many current jet-propelled fighters there is a trend toward dispersing much of the fuel in external wing-tip tanks which may in some instances be permanently attached to the wing. With wing-tip tanks installed, the mass distribution of the airplane changes as the fuel is used and the spin and recovery characteristics may vary with this change in loading.

In accordance with the request of the Bureau of Aeronautics, Department of the Navy, tests have been made in the Langley 20-foot free-spinning tunnel to determine the effect on the spin and recovery characteristics of changing load in external wing-tip tanks on a $\frac{1}{24}$ -scale model of the Grumman XF9F-2 airplane. Tests were performed previously in the Langley 20-foot free-spinning tunnel on the $\frac{1}{24}$ -scale model without external wing-tip tanks. The results of those tests were reported in reference 1.

SYMBOLS

b	wing span, feet
S	wing area, square feet
c	wing or elevator chord at any station along span
\bar{c}	mean aerodynamic chord (M.A.C.), feet
x/\bar{c}	ratio of distance of center of gravity rearward of leading edge of mean aerodynamic chord to mean aerodynamic chord
z/\bar{c}	ratio of distance between center of gravity and thrust line to mean aerodynamic chord (positive when c.g. is below thrust line)
m	mass of airplane, slugs
I_X, I_Y, I_Z	moments of inertia about X, Y, and Z body axes, respectively, slug-feet ²
$\frac{I_X - I_Y}{mb^2}$	inertia yawing-moment parameter
$\frac{I_Y - I_Z}{mb^2}$	inertia rolling-moment parameter
$\frac{I_Z - I_X}{mb^2}$	inertia pitching-moment parameter

ρ	air density, slugs per cubic foot
μ	relative density of airplane $\left(\frac{m}{\rho S b}\right)$
α	angle between thrust line and vertical (approx. equal to absolute value of angle of attack at plane of symmetry), degrees
ϕ	angle between span axis and horizontal, degrees
V	full-scale true rate of descent, feet per second
Ω	full-scale angular velocity about spin axis, revolutions per second
σ	helix angle; angle between flight path and vertical, degrees (For the tests of this model, the average absolute value of the helix angle was approx. 4°).
β	approximate angle of sideslip at center of gravity, degrees (Sideslip is inward when inner wing is down by an amount greater than the helix angle.)

APPARATUS AND METHODS

Model

The $\frac{1}{24}$ -scale model of the Grumman XF9F-2 used for the tests of reference 1 was modified to represent the new configuration by the addition of external wing-tip tanks and by reballasting the model to obtain dynamic similarity to the airplane with external wing-tip tanks at an altitude of 20,000 feet ($\rho = 0.001267$ slug per cubic foot). A three-view drawing of the model as tested is shown in figure 1. The dimensional characteristics of the model as tested are given in table I. The tail-damping power factor was computed by the method given in reference 2.

Wind Tunnel and Testing Technique

The technique used for obtaining and converting data was the same as that used for the original XF9F-2 model tests. (See reference 1.)

Spin-tunnel tests are usually made to determine the spin and recovery characteristics of the model at the normal spinning control configuration (elevator full up, ailerons neutral, and rudder full with the spin) and at various other aileron-elevator control combinations, including zero and maximum deflections. Recovery is attempted either by rapid full rudder reversal alone or by simultaneous rapid full rudder and elevator reversal. Tests are also performed to evaluate the possible adverse effects on recovery of small control deviations from the normal control configuration for spinning. For these tests, the ailerons are set at one-third of the full deflection in the direction of the slower recoveries and the elevator is set at full up or two-thirds of its full-up deflection, whichever will cause slower recoveries. Recovery is attempted either by rapid rudder reversal alone from full with the spin to two-thirds against the spin or by simultaneous rapid rudder reversal from full with the spin to two-thirds against the spin and movement of the elevator down. This control configuration and movement is referred to as the "criterion spin." Recovery characteristics of the model are considered satisfactory if recovery from this criterion spin requires $2\frac{1}{4}$ turns or less. This value has been selected on the basis of full-scale airplane spin-recovery data that are available for comparison with corresponding model test results.

If rudder and elevator reversal are used for recovery, simultaneous movement of these controls is used as a matter of testing convenience. It is felt that moving rudder and elevator simultaneously leads to a somewhat conservative result inasmuch as the rudder is shielded somewhat by the elevator moving downward as the rudder is moving against the spin.

PRECISION

The precision of the measurements made and of the data presented is believed to be the same as that listed in reference 1.

Test Conditions

Tests of the model with external wing-tip tanks were made only for erect spins, clean condition (flaps and landing gear retracted). The mass characteristics and inertia parameters of the airplane and of the model as tested are shown in table II and plotted in figure 2. As discussed in reference 3, figure 2 can be used as an aid in predicting the relative effectiveness of the controls on the recovery

characteristics of the model. Figure 3 presents an empirical criterion which can be used to give an indication of the expected recovery characteristics of a design as explained in reference 2.

The maximum control deflections used for the current tests were:

Rudder, deg	30 right, 30 left
Elevator, deg	35 up, 10 down
Ailerons, deg	20 up, 15 down

Intermediate control deflections used were:

Rudder, two-thirds deflected, deg	20
Elevator, two-thirds up, deg	$23\frac{1}{3}$
Elevator, two-thirds down, deg	$6\frac{2}{3}$
Ailerons, one-third deflected, deg	$\frac{62}{3}$ up, 5 down

RESULTS AND DISCUSSION

A preliminary analysis of the proposed tests of the XF9F-2 model was made using figure 3. When the model parameters were plotted on this chart, it was noted that, with the wing-tip tanks one-third full, the model fell in a region where the expected recovery characteristics might be unsatisfactory. As explained in reference 2, this portion of the chart is conservative in that satisfactory models may fall under the dividing line, but no unsatisfactory models fall above the line. It was therefore decided to run tests with the model ballasted for this condition and other loadings which would give a representative picture of the spin and recovery characteristics for the model at any possible loading. The results of the model tests at four representative loadings are presented in charts 1 to 4 and discussed below.

The model data are presented in terms of the full-scale values for the airplane at a test altitude of 20,000 feet. Right- and left-spin results were generally similar, and the results considered slightly conservative were arbitrarily presented in terms of right spins. For the condition with tanks one-third full, however, there was an appreciable difference in results to the right and left, apparently due to inadvertent asymmetry of the model associated with damage during testing, and, accordingly, the results obtained in both directions are presented.

Tanks empty.— The results of erect spin tests of the model with tanks installed at the wing tips (loading point 1 in table II and fig. 2) are shown in chart 1. The data show that the spins were oscillatory, mostly in roll and yaw, and that recoveries by rudder reversal were satisfactory.

Tanks one-third full.— Erect-spin-test data with the tanks one-third full (loading point 2 in table II and fig. 2) are presented in chart 2. As stated previously, results for right and left spins were not similar. Left spins were steep and recoveries by full rudder reversal were rapid, but right spins were flatter and recoveries slower with two and one-half turns being required for recovery from the criterion spin, which is just over the border line for satisfactory recoveries. It is felt that an average of the model right and left spins will indicate the behavior of the airplane. It can be seen that an average of the results indicates satisfactory recoveries by rudder reversal. Simultaneous reversal of the rudder and elevator led to four-turn recoveries. This was considered as an indication that, for this loading, movement of the elevator down simultaneously with rudder movement probably shielded the rudder somewhat, thus rendering it less effective. Normal use of controls (full rapid rudder reversal, followed approx. one-half turn later by movement of the elevator down) would prevent this.

Tanks three-fourths full.— Erect-spin-test data with the tanks three-fourths full (loading point 3 in table II and fig. 2) are presented in chart 3. The results show that the spins were oscillatory in roll, yaw, and pitch and that recoveries from the criterion spin by rudder reversal alone were unsatisfactory. When the rudder was reversed from full with the spin to two-thirds against simultaneously with moving the elevator from full up to two-thirds down, the model either recovered in two turns or had not quite recovered at the end of two turns. This was considered as an indication that the model was on the verge of satisfactory recovery. For this spin, satisfactory recoveries were obtained by simultaneous rudder reversal from full with to two-thirds against the spin and movement of the elevator from full up to full down.

Tanks full.— The results of spin tests of the model with fully loaded tanks (loading point 4 in table II and fig. 2) are presented in chart 4. The spins were oscillatory, mainly in pitch, and recoveries were similar to those obtained when the wing-tip tanks were three-fourths full. Reversal of the rudder in conjunction with movement of the elevator to full down led to a satisfactory recovery from the criterion spin.

Control Forces

The discussion of the results has been based on control effectiveness alone without regard to the forces required to move the controls. Sufficient force was applied to the controls to move them fully and rapidly for all tests. Sufficient force must be applied to the airplane controls to move them in a similar manner in order for the model and airplane results to be comparable.

Calculations were made based on the information in references 4 and 5 to determine the expected control forces. The forces were of the magnitude of 100 and 150 pounds for the rudder and elevator, respectively. These calculations are qualitative and are felt to be somewhat conservative; however, inasmuch as the maximum stick push force for an average pilot using one hand is of the order of 120 pounds (reference 6), it is felt that these calculations indicate that the elevator force on the XF9F-2 may be excessive and some type of balance or booster may be required.

Jettisoning Wing-Tip Tanks

Information is not available as to whether jettisoning of the wing-tip tanks is possible on the XF9F-2. It is felt that inasmuch as with tanks installed, it will be necessary to move the elevator down to obtain satisfactory recovery from a fully developed spin, and inasmuch as the elevator stick force may be excessive, it is desirable that the tanks be made jettisonable so that recovery will be attainable without movement of the elevator down.

Spin-tunnel experience has indicated that when wing-tip tanks are jettisoned in a spin, the tanks will not hit any part of the airplane.

Aerodynamic Effect of Tanks

Results obtained for the model with tanks empty and corresponding results in reference 1 for the model without tip tanks were similar. This was taken as an indication that there was no appreciable aerodynamic effect of tip tanks upon spin and recovery characteristics.

Recommended Recovery Technique

Based on the results obtained for the model, the following recommendation is made as to recovery technique for the XF9F-2 airplane. The rudder should be reversed briskly from full with the spin to full against the spin, followed approximately one-half turn later by

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movement of the elevator full down while keeping the ailerons neutral. Care should be exercised to avoid premature movement of the elevator and of excessive rates of acceleration in the recovery dive.

CONCLUSIONS

The results of spin tests of a $\frac{1}{24}$ -scale model of the Grumman XF9F-2 airplane with tip tanks installed indicated the following conclusions regarding the spin and recovery characteristics of the airplane at a spin altitude of 20,000 feet:

1. Recoveries will be satisfactory and it is recommended that for all loadings, recovery be attempted by briskly reversing the rudder fully, followed approximately one-half turn later by movement of the elevator full down while keeping the ailerons neutral; care should be exercised to avoid premature movement of the elevator and of excessive accelerations in the recovery dive. The spins will be oscillatory, mainly in roll and yaw when the tanks are empty, changing to oscillations in pitch as the full-tank loading is approached.

2. The rudder control force for spin recovery will be within the physical capability of the pilot for spin recovery; however, the elevator control force for spin recovery might be excessive so that some type of balance or booster may be required, or it might be necessary to jettison the wing-tip tanks.

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4. Stone, Ralph W., Jr., and Burk, Sanger M., Jr.: Effect of Horizontal-Tail Position on the Hinge Moments of an Unbalanced Rudder in Attitudes Simulating Spin Conditions. NACA TN 1337, 1947.
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TABLE I.- DIMENSIONAL CHARACTERISTICS OF GRUMMAN

XF9F-2 AIRPLANE WITH WING-TIP TANKS

Length, over all, ft	37.58
Center-of-gravity location, percent \bar{c}	25.1
Wing:	
Span, ft	37.7
Area, sq ft	250
Section	NACA 64 ₁ -A012
L.E. wing at root to elevator hinge, ft	20.5
Incidence, deg	0
Dihedral, deg	4
Aspect ratio	4.97
Leading edge of \bar{c} rearward of L.E. of wing, in.	7.5
Mean aerodynamic chord, in.	89.4
Sweepback at 27 percent c, deg	0
Ailerons:	
Span, ft	5.6
Area aft hinge line, sq ft	17.6
Hinge line, percent c	71.7
Horizontal tail:	
Span, ft	16.2
Total area, sq ft	60
Elevator area aft hinge line, sq ft	18.48
Incidence, deg	0
Vertical tail:	
Total area, sq ft	34.89
Total rudder area aft hinge line, sq ft	5.92
Tail-damping ratio	0.0457
Unshielded-rudder-volume coefficient	0.0128
Tail-damping power factor	0.000585



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TABLE II.-- MASS CHARACTERISTICS AND INERTIA PARAMETERS FOR LOADING CONDITIONS

POSSIBLE ON GRUMMAN XF9F-2 AIRPLANE WITH WING-TIP TANKS

INSTALLED AND FOR LOADINGS TESTED ON $\frac{1}{24}$ -SCALE MODEL

[Model values converted to corresponding full-scale values; moments of inertia given about center of gravity]

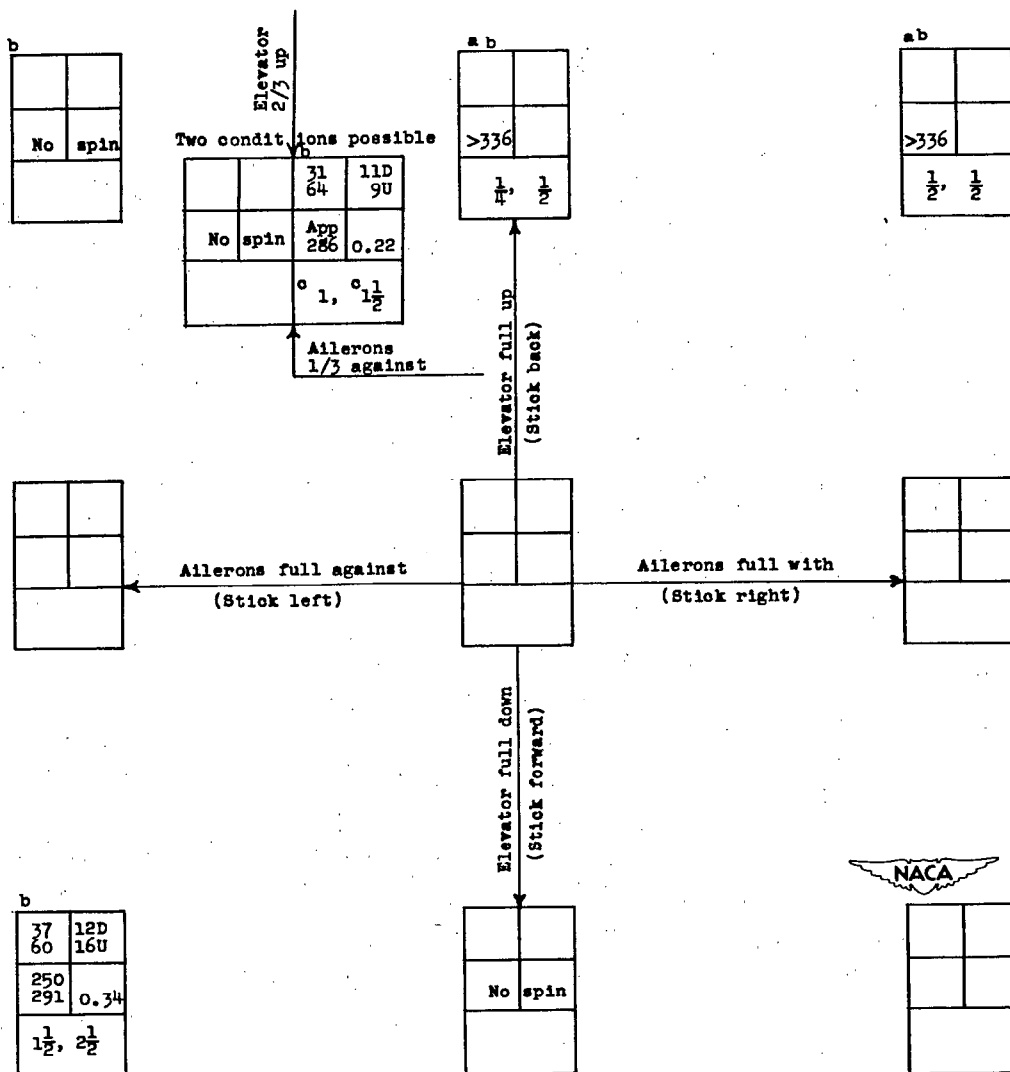
Number	Loading	Weight (lb)	μ sea level	μ 20,000 feet	Center-of- gravity location		Moments of inertia (slug-ft ²)			Mass parameters		
					x/\bar{c}	z/\bar{c}	I_X	I_Y	I_Z	$\frac{I_X - I_Y}{mb^2}$	$\frac{I_Y - I_Z}{mb^2}$	$\frac{I_Z - I_X}{mb^2}$
Airplane values												
1	Tip tanks on and empty (basic flight)	13,000	18.0	33.8	0.240	0.007	7,725	19,496	25,675	-205×10^{-4}	-108×10^{-4}	313×10^{-4}
2	Tip tanks one-third full	13,480	18.7	35.0	.240	0	12,555	19,496	30,505	-117	-185	302
3	Tip tanks three-fourths full	14,900	20.6	38.7	.251	-.010	18,751	19,852	36,891	-17	-259	276
4	Tip tanks full	15,260	21.2	39.7	.251	-.010	22,715	19,852	40,855	43	-312	269
Model values												
1	Tip tanks on and empty (basic flight)	12,872	17.8	33.5	0.239	0.001	7,248	19,450	24,510	-216×10^{-4}	-89×10^{-4}	304×10^{-4}
2	Tip tanks one-third full	13,580	18.8	35.4	.247	.0103	12,596	19,657	30,524	-117	-181	298
3	Tip tanks three-fourths full	14,870	20.6	38.7	.257	.037	20,716	21,079	39,627	-6	-282	288
4	Tip tanks full	15,331	21.3	39.9	.244	-.031	22,620	19,740	40,185	43	-302	260

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CHART 1.- SPIN AND RECOVERY CHARACTERISTICS OF THE $\frac{1}{4}$ -SCALE MODEL OF THE GRUMMAN
XF9F-2 AIRPLANE WITH THE WING-TIP TANKS EMPTY

[Loading point 1 in table II and figure 2; flaps neutral; cockpit closed; recovery attempted by rapid full rudder reversal except as noted (recovery attempted from, and steady-spin data presented for, rudder-with spins); right erect spins]



^a Steep spin, could not get steady data.

^b Oscillatory in roll and yaw. Average value or range of values given.

^c Recovery attempted by reversal of rudder from full with to $\frac{2}{3}$ against the spin.

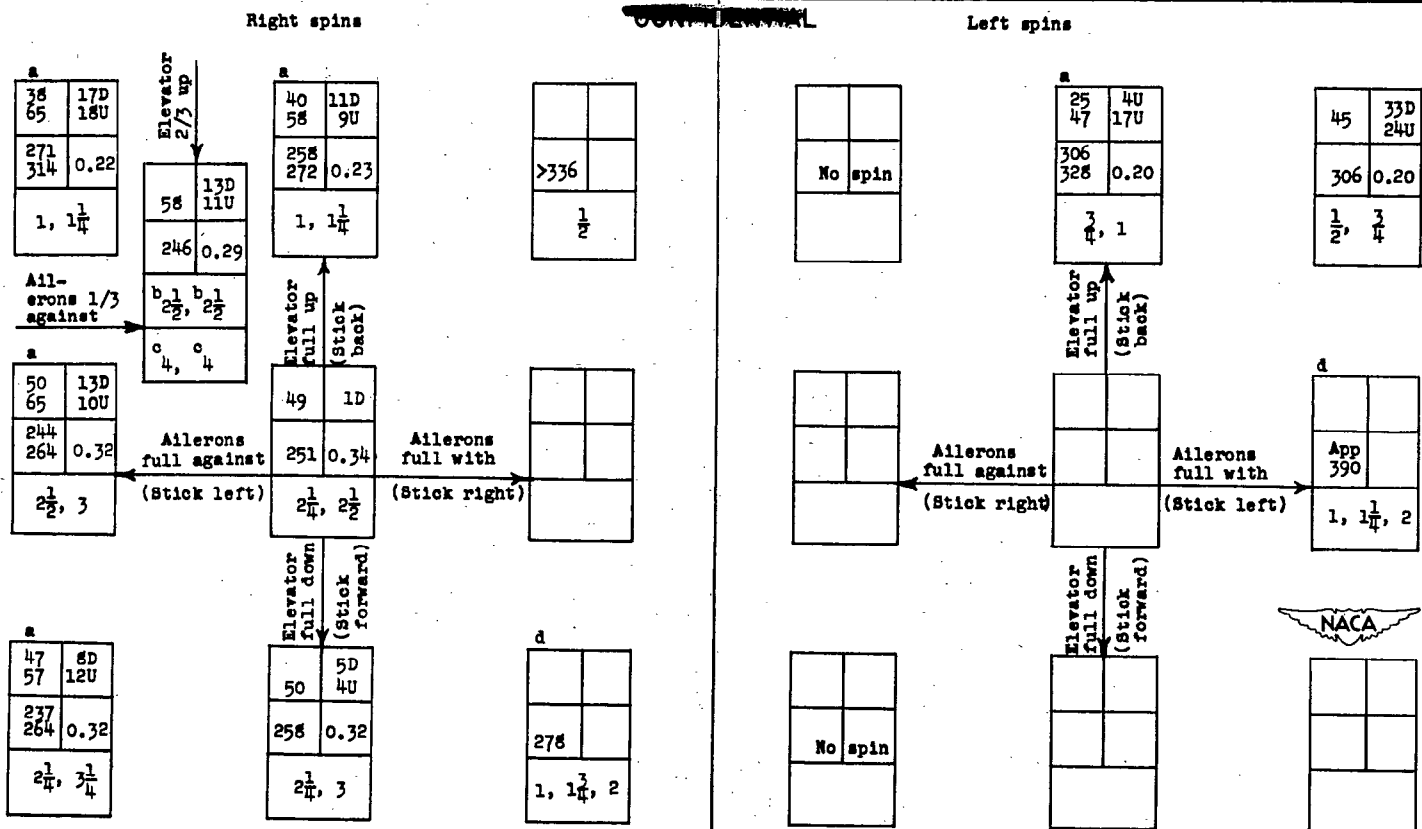
Model values converted to corresponding full-scale values.
U inner wing up
D inner wing down

α (deg)	ϕ (deg)
V (fps)	Ω (rps)
Turns for recovery	

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CHART 2.- SPIN AND RECOVERY CHARACTERISTICS OF THE $\frac{1}{24}$ -SCALE MODEL OF THE GRUMMAN XF9F-2 AIRPLANE WITH THE WING-TIP TANKS ONE-THIRD FULL

[Loading point 2 in table II and figure 2; flaps neutral; cockpit closed; recovery attempted by rapid full rudder reversal except as noted (recovery attempted from, and steady-spin data presented for, rudder-with spins); right and left erect spins]



^aOscillatory in roll and yaw. Average value or range of values given.
^bRecovery attempted by reversal of the rudder from full with to $2/3$ against the spin.
^cRecovery attempted by simultaneous reversal of the rudder from full with to $2/3$ against the spin and elevators from $2/3$ up to full down.
^dWandering spin, could not get steady data.

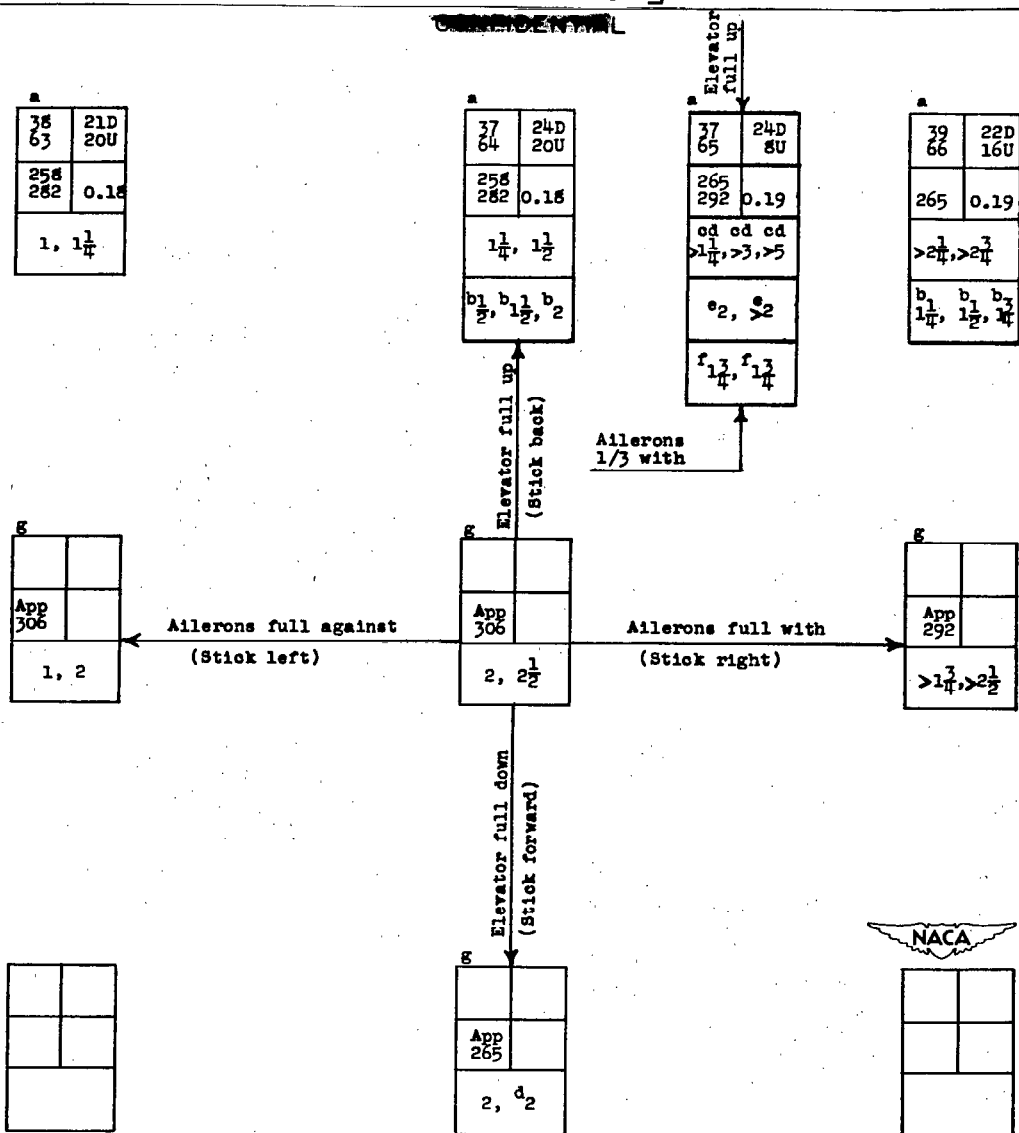
Model values converted to corresponding full-scale values.
 U inner wing up
 D inner wing down

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α (deg)	ϕ (deg)
V (fps)	Ω (rps)
Turns for recovery	

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CHART 3.- SPIN AND RECOVERY CHARACTERISTICS OF THE $\frac{1}{24}$ -SCALE MODEL OF THE GRUMMAN XF9F-2 AIRPLANE WITH THE WING-TIP TANKS THREE-FOURTHS FULL

[Loading point 3 in table II and figure 2; flaps neutral; cockpit closed; recovery attempted by rapid full rudder reversal except as noted (recovery attempted from, and steady-spin data presented for, rudder-with spins); right erect spins]



^aOscillatory in roll, pitch, and yaw. Average value or range of values given.

^bRecovery attempted by simultaneous full reversal of rudder and elevator.

^cRecovery attempted by reversal of rudder from full with to 2/3 against the spin.

^dVisual observation.

^eRecovery attempted by simultaneous reversal of the rudder from full with to 2/3 against the spin and of the elevator from full up to 2/3 down.

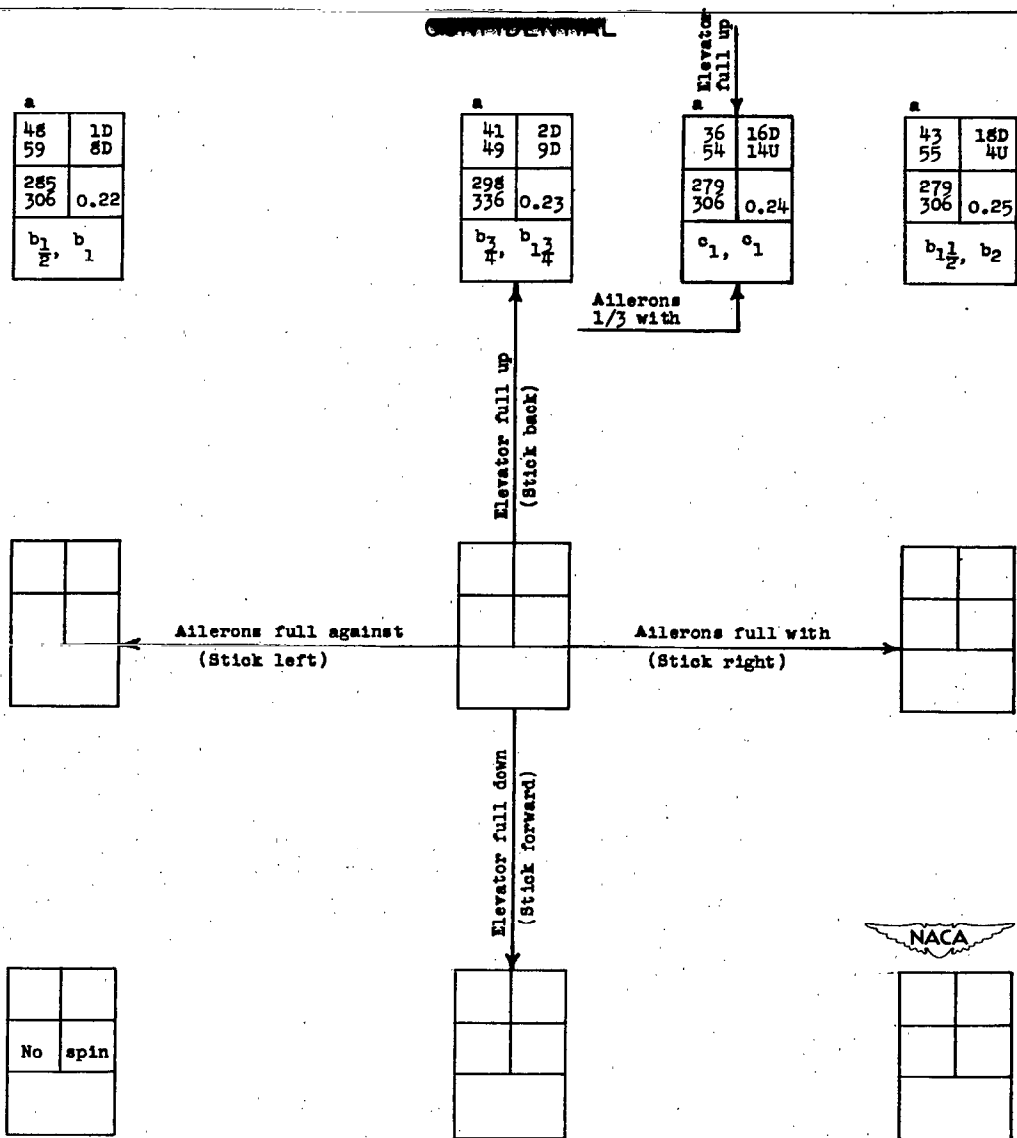
^fRecovery attempted by simultaneous reversal of the rudder from full with to 2/3 against the spin and of the elevator from full up to full down.

^gWandering spin, could not get steady-spin data.

Model values converted to corresponding full-scale values.
U inner wing up
D inner wing down

a (deg)	φ (deg)
V (fps)	Ω (rps)
Turns for recovery	

[Loading point 4 in table II and figure 2; flaps neutral; cockpit closed (recovery attempted from, and steady-spin data presented for, rudder-with spines); right erect spine]



Model values
converted to
corresponding
full-scale values.
U inner wing up
D inner wing down

α (deg)	ϕ (deg)
V (fps)	Ω (rps)
Turns for recovery	

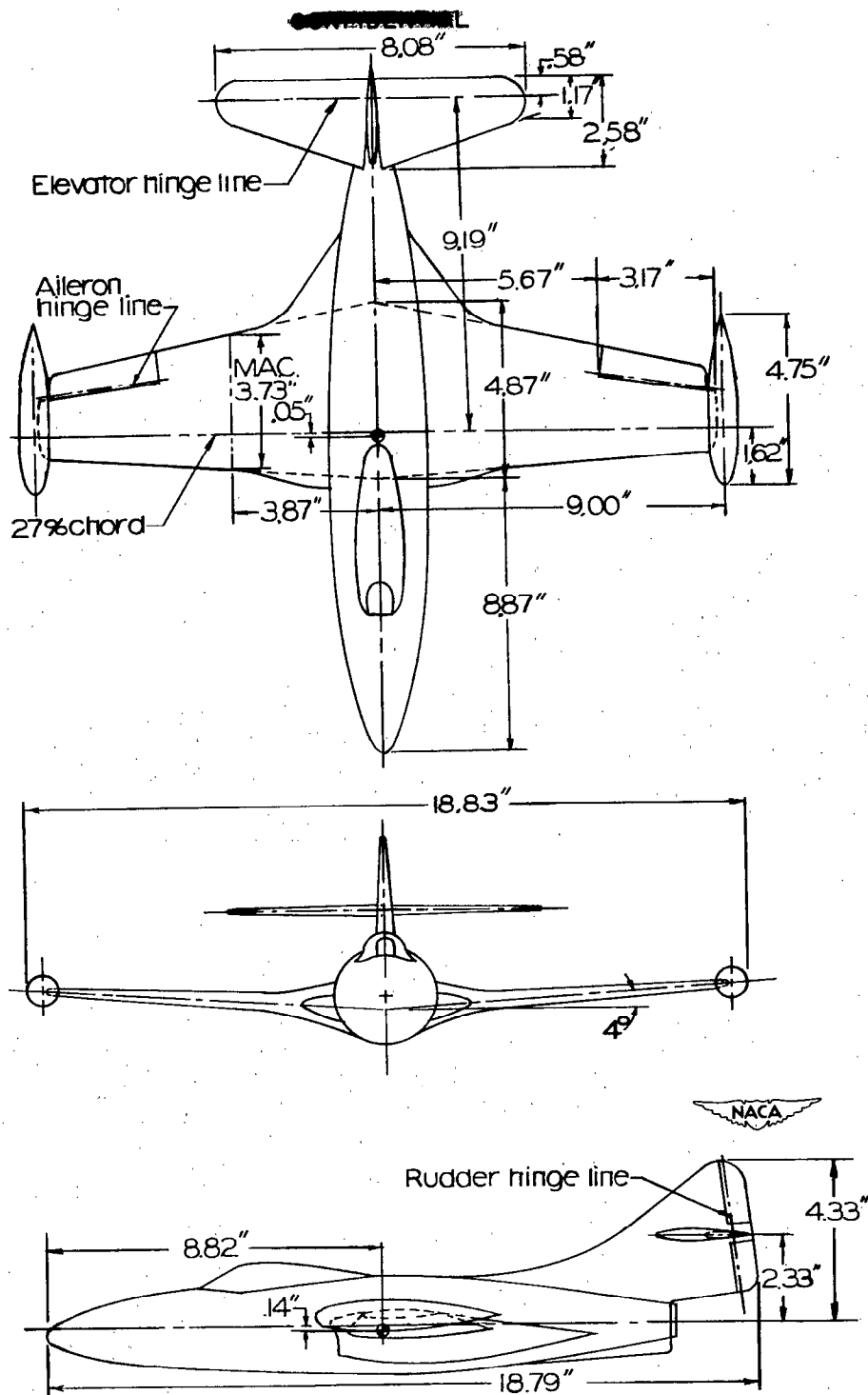


Figure 1: Three-view drawing of the $\frac{1}{24}$ scale model of the Grumman XF9F2 airplane with tip tanks installed as tested in the free-spinning tunnel.

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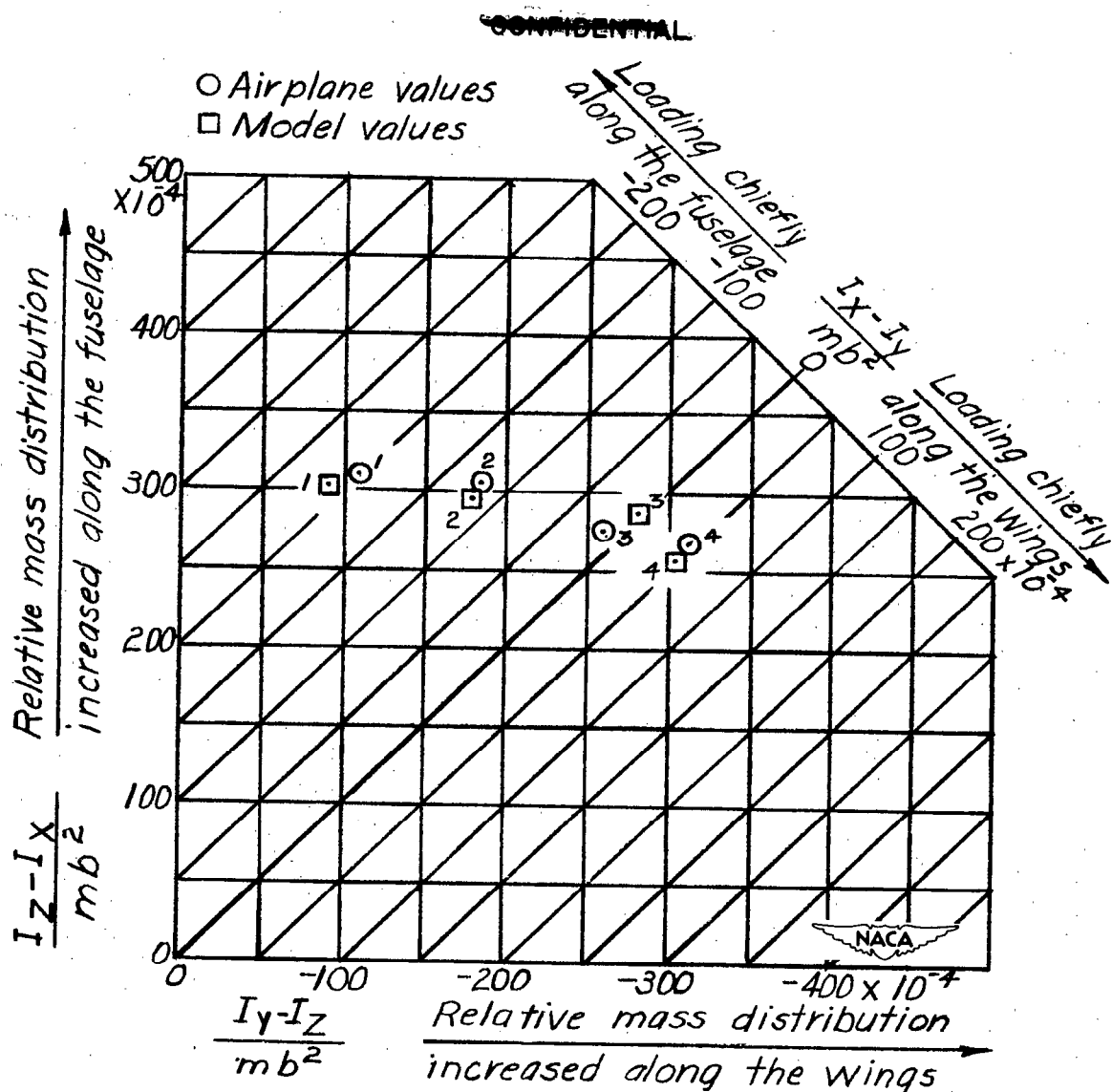


Figure 2.-Mass parameters for loadings possible on the XF9F-2 airplane and for loadings tested on the model (Points are for loadings listed in table II.)

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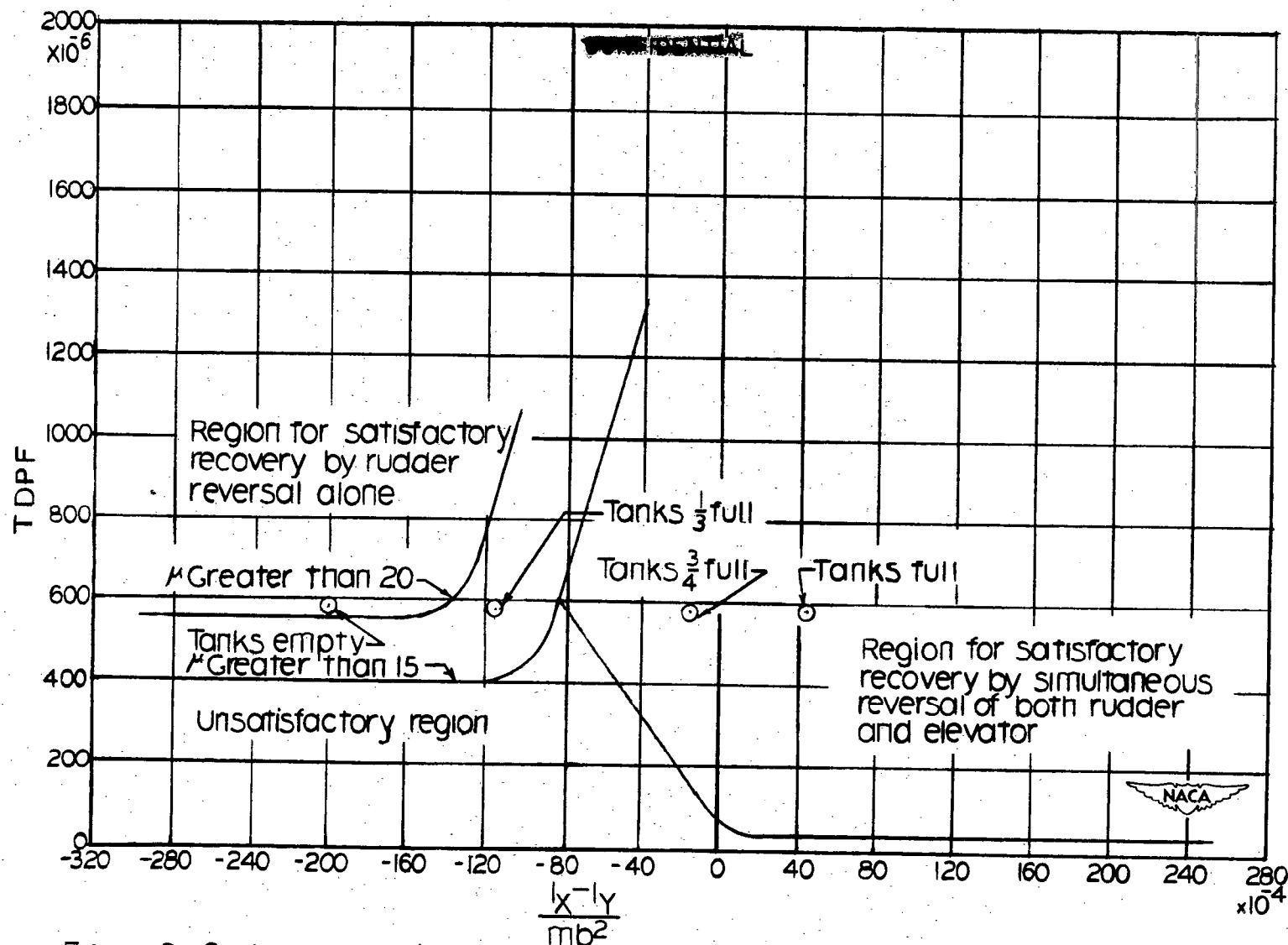


Figure 3.- Spin-recovery design requirements.

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